# Simulating the RFOFO ring using GEANT

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(updated version)

# OUTLINE

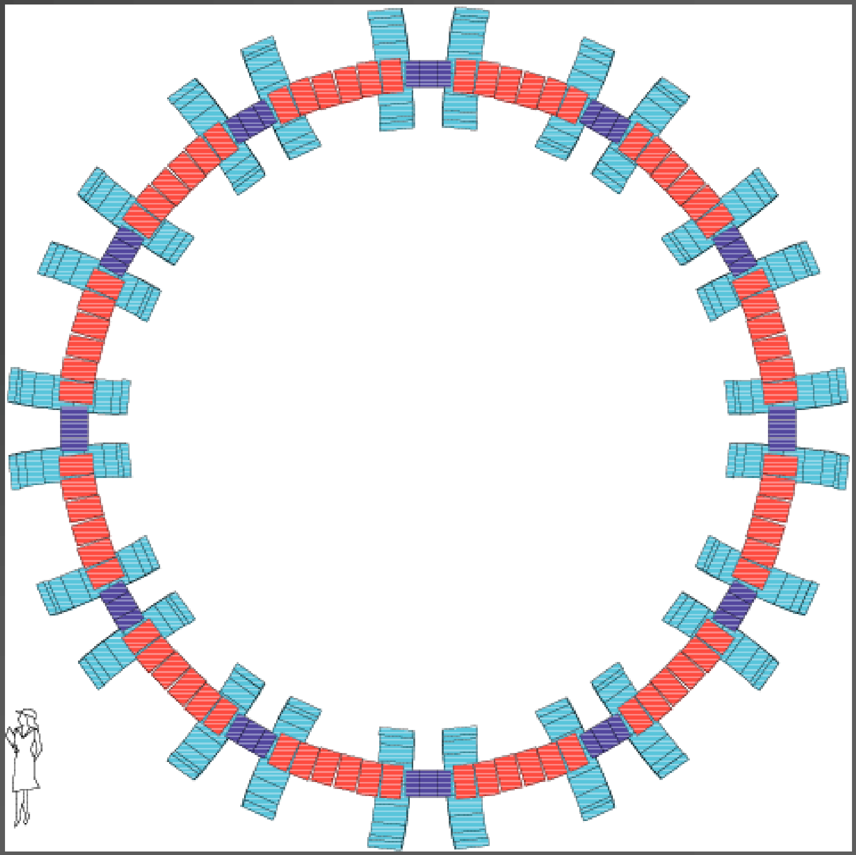
- Geometry and magnetic field
- Setting the parameters
  - Reference orbit
  - Defining the clock
- Single particles in the ring
  - “Cooling” with an Ideal Absorber
  - Acceptance and RF parameters
- Cooling of a beam
  - With/without muon decay
  - Comparing to other results
  - Problems…

# Basic ingredients

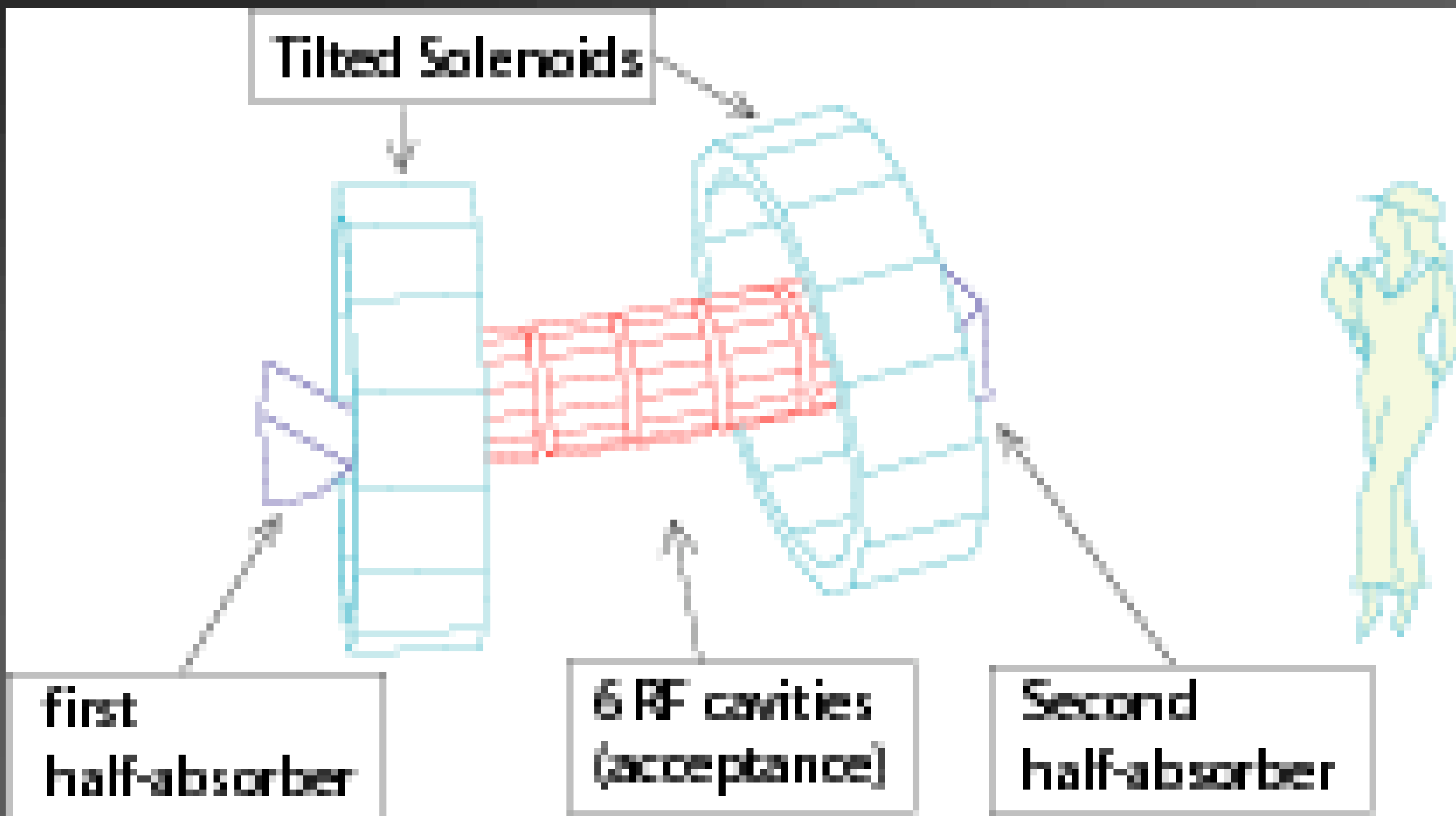
- Simulation software – GEANT 3.21, as used in Tetra ring simulations (R. Raja, R. Godang)
- Geometry from R. Fernow, V. Balbekov (MC-Note 264)
- Magnetic field maps provided by Mississippi (R. Godang, S. Bracker, see also MC-Note 271)

# The ring geometry

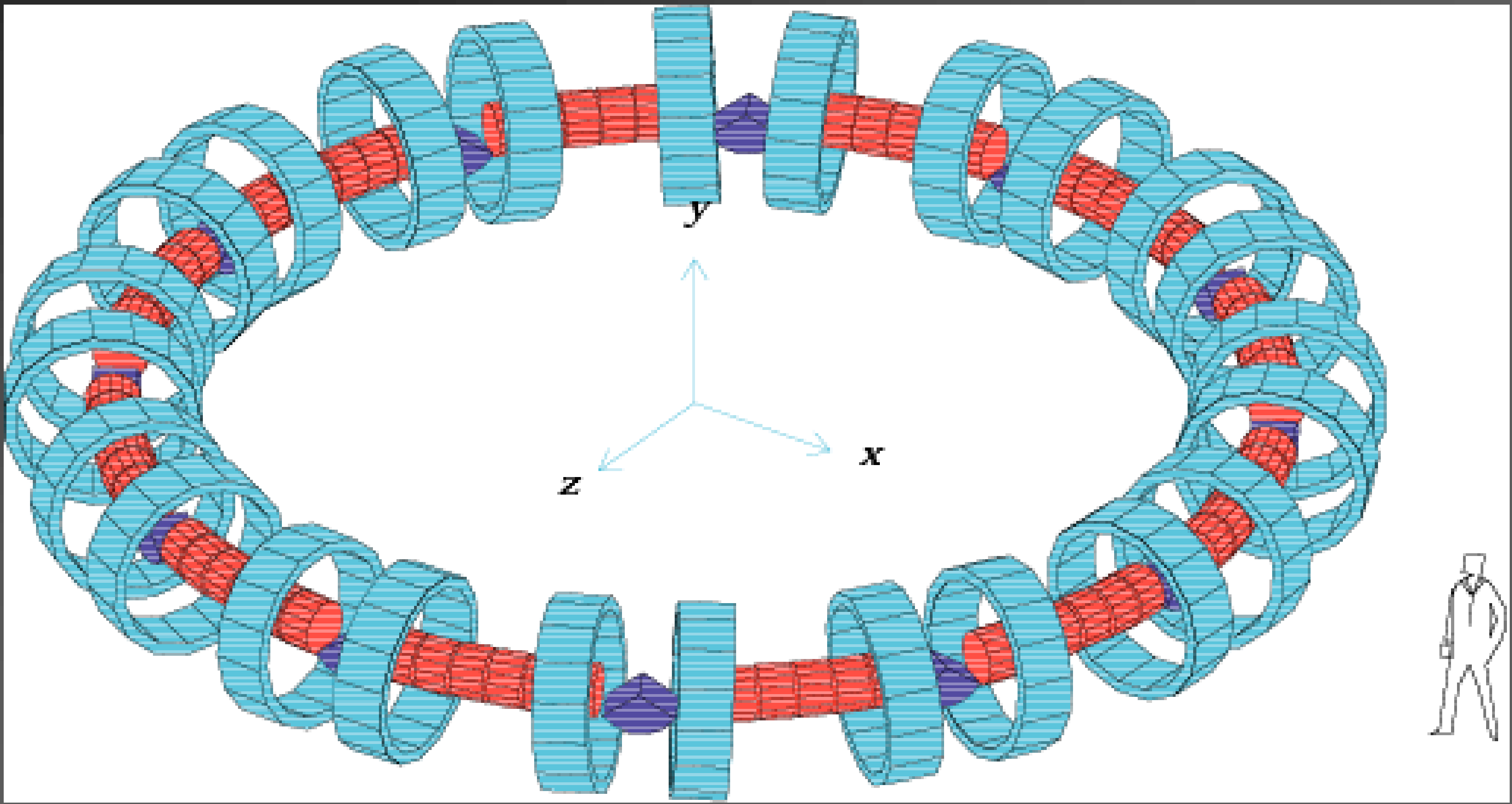
- 33 m circumference
- 12 cells (2.75m):
  - A wedge absorber
    opening angle 110°,
    pointing “upwards’
  - 6 RF cavities
    28.75 cm long,
    acceptance radius 25 cm
  - 2 tilted solenoids
    inner/outer r = 77/88 cm
    tilt angle ±3°
    Only for display here…



# A view of a single cell



# 3-D view of the RFOFO ring



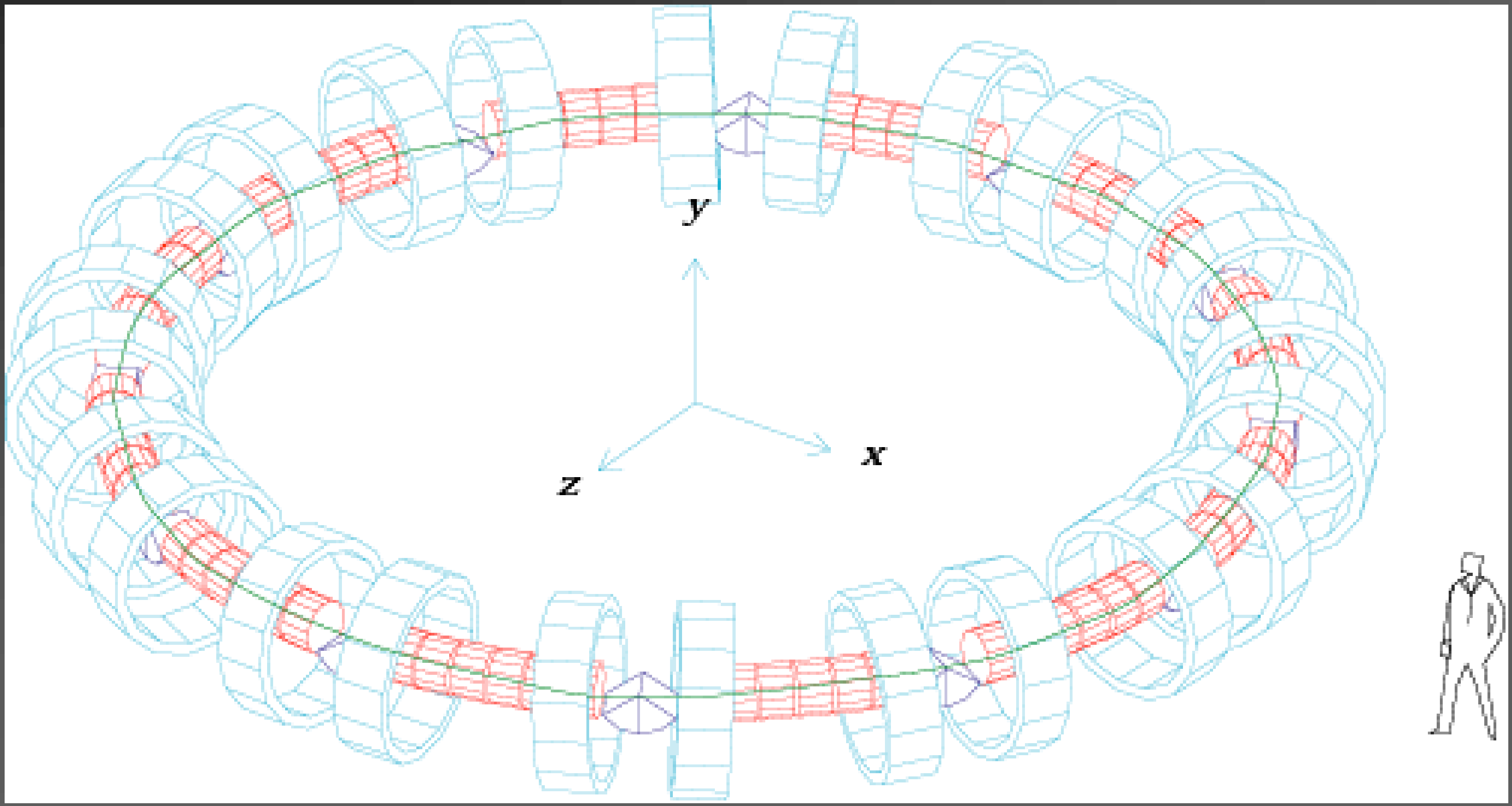
# Defining the ring parameters

- Find the "reference orbit"
  - Run without RF acceleration or absorbers
  - Find a closed orbit (also periodic in cells)
- Start in the middle of the absorber

  It's one of 2 point in which the initial $p_T$ vanishes (for obvious symmetry reasons)

  It's also where the cell "begins"…

# Running without RF & absorbers



# Only with the magnetic field on,

- The ring is stable for a range of initial $p_z$'s
  ~165–260 MeV/c

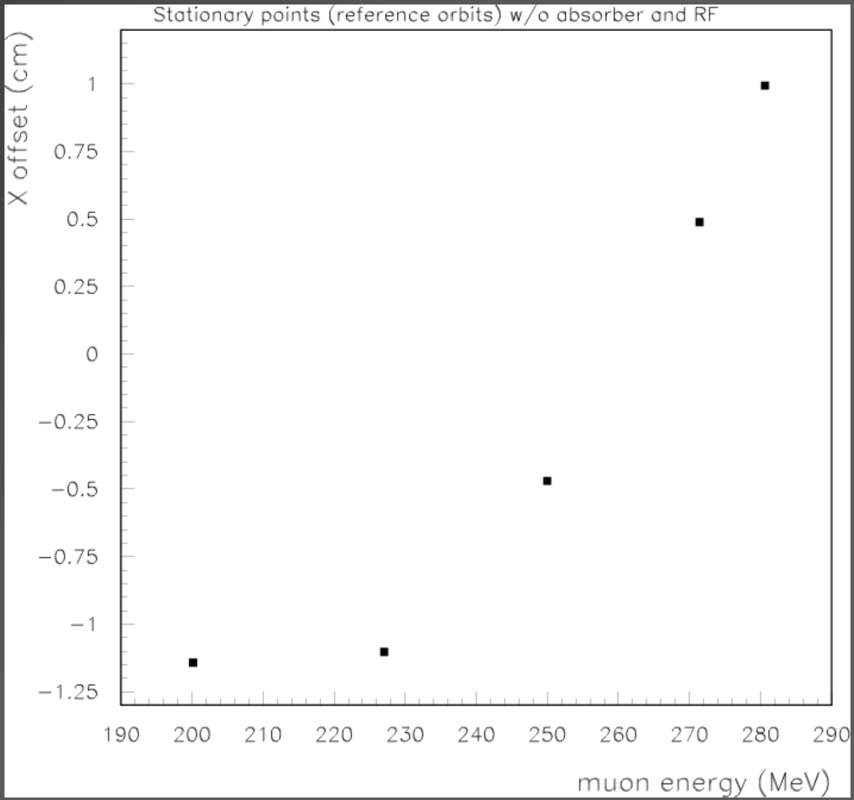
- The strategy:
  - for each $P_z$, find a "stationary point" in the half-wedge plane, where the muon returns to the same x,y in every cell
  - Check x and y dependence on initial energy to find best position and direction of the absorber
  - Find a "clock" – to set the entry times of RF cavities

  Then RF and absorber can be turned on

# Dispersion function at half-wedge: horizontal coordinate

- No linear dependence

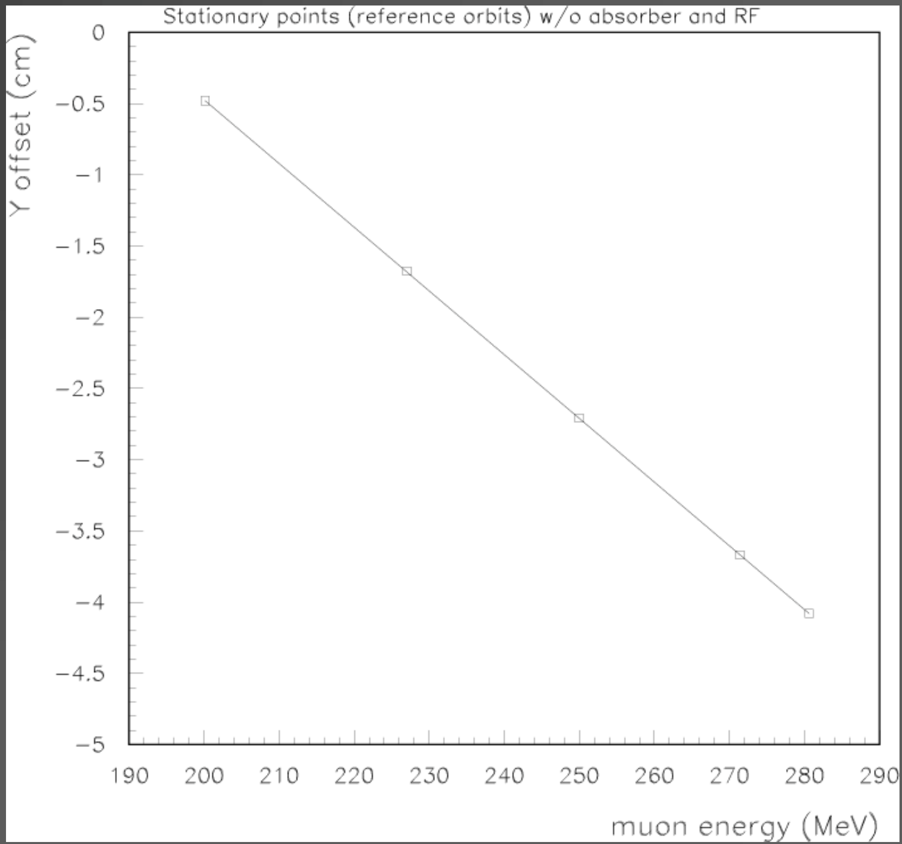
  especially at low energy



# Dispersion function at half-wedge: vertical coordinate

- Linear dependence in the y direction:

To 1st order – wedges with straight walls point upwards



# Setting the clock

- RF frequency: f = 201.25 MHz
  - Set the entry times of the cavities:

    run a muon in the ring (without RF & absorber) with a rotation period of an integer multiple 1/f.
- For $p_z$=200.96 MeV/c (E227 MeV)

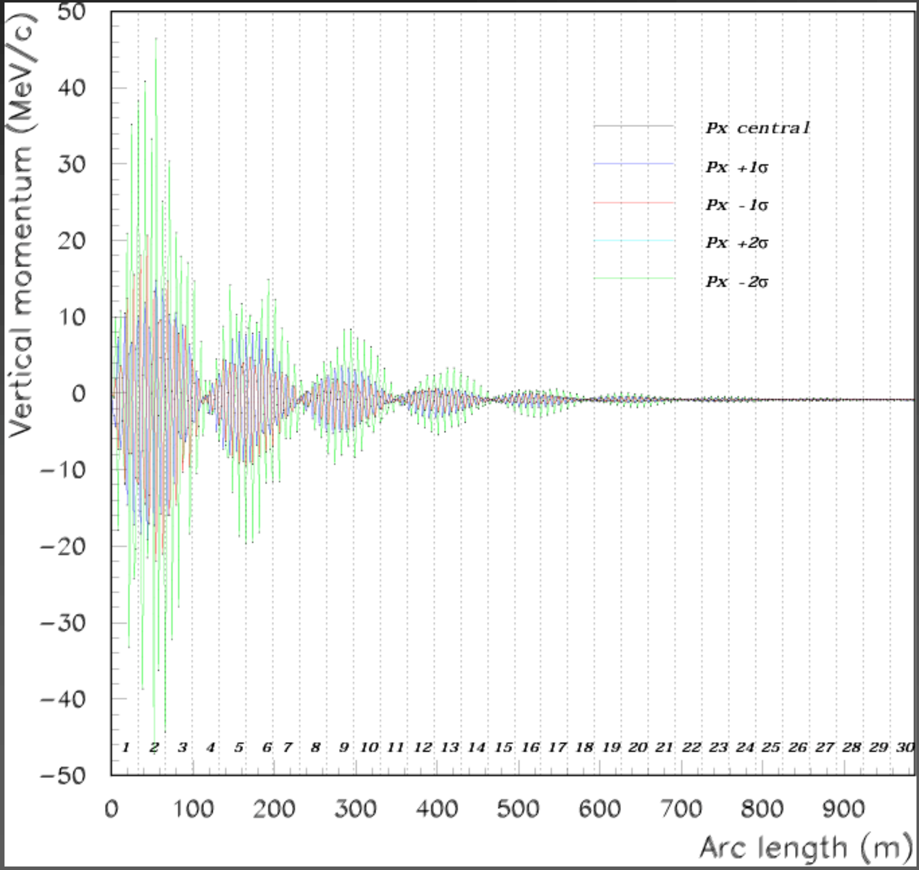
   the 25th harmonic

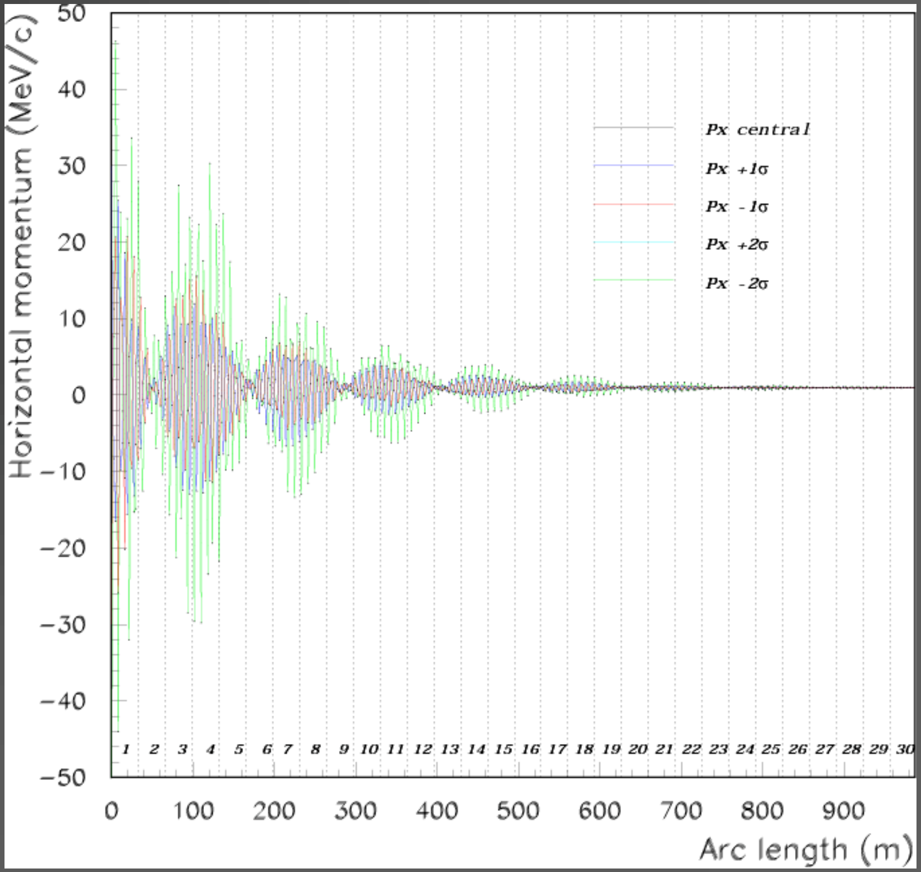
  (actually, 201.26 MHz was the closest I could get)

# Turn on the RF and absorber

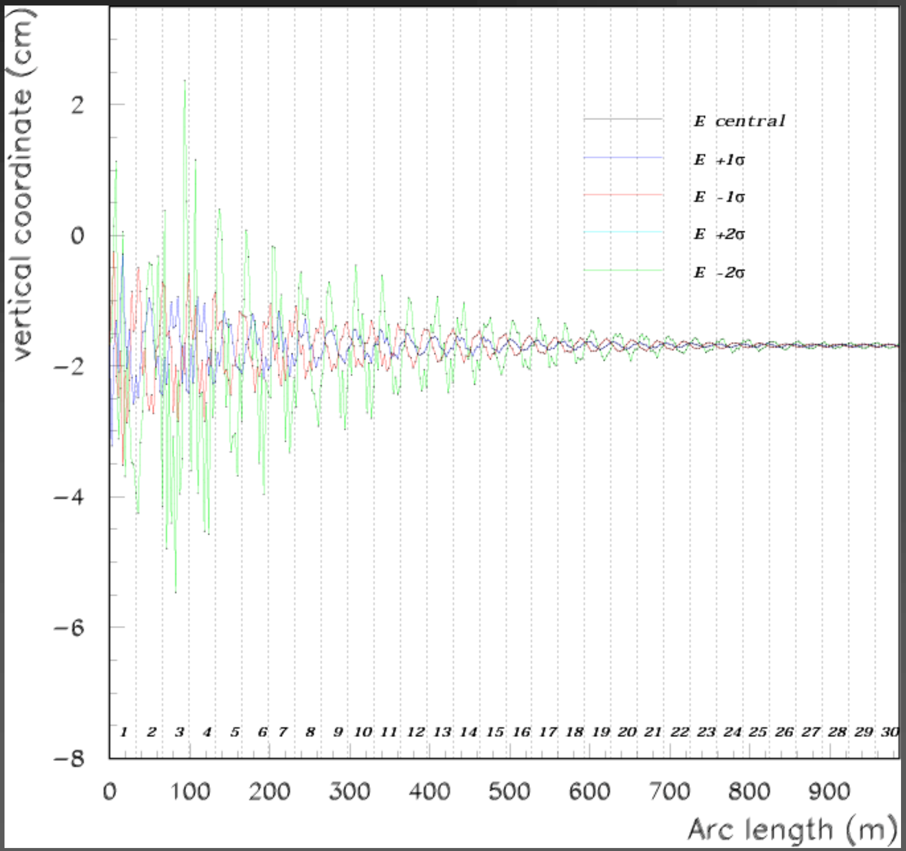
- First, use an ideal absorber
  - no multiple scattering, straggling, or other processes
- RF electric field “a la Tetra”:
  - In the cavity volume (cavity coordinates): $E_x=E_y=0$, $E_z=G\cdot\sin[\square(t-t_{ent})+\square_{ent}]$, independent of point in space
  - (I used G=13.5 MV/m, $\square_{ent}=-13°$ for the single-particle simulation)
- See what happens when injecting muons from various points in parameter space
  - central value, ±1,2□ (Gaussian beam from MC-264)

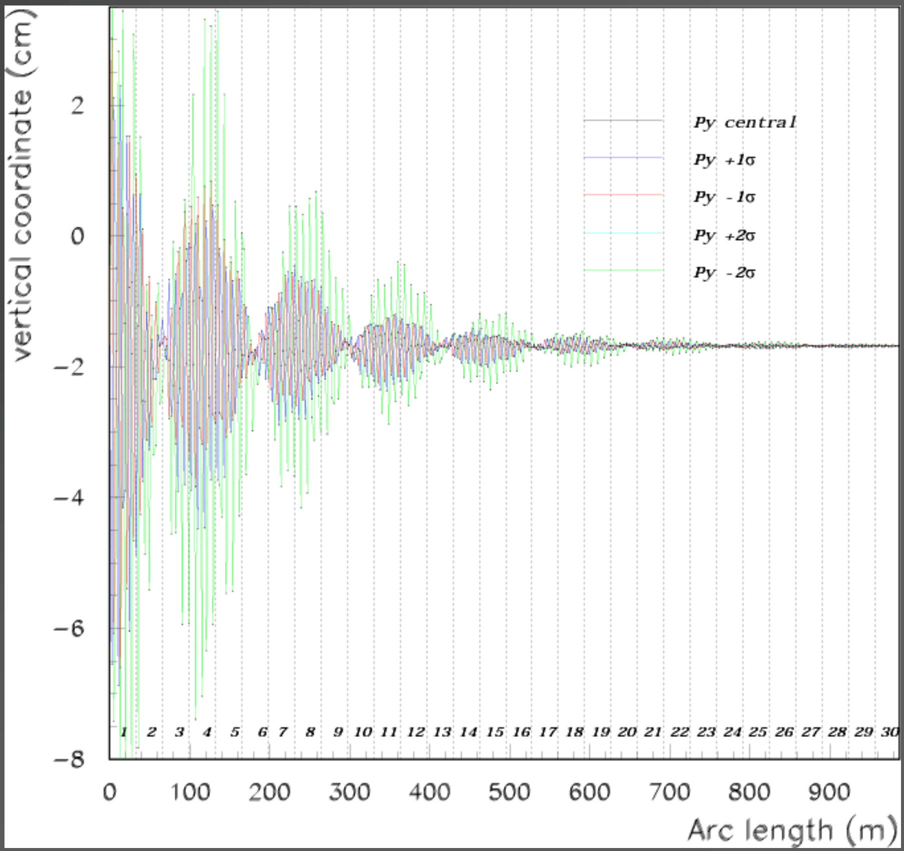
# Perfect absorber – perfect cooling



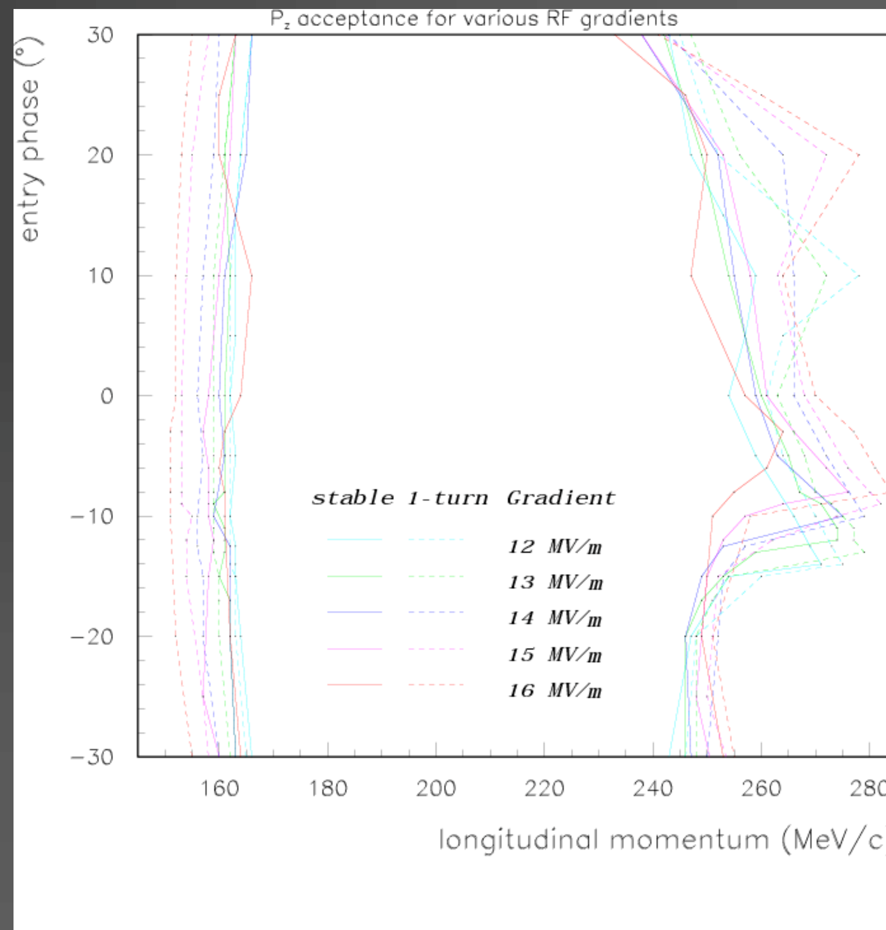
# y evolution for various initial E, $p_y$



# RF gradient and acceptance

- Acceptance depends on RF parameters:
  - Gradient, G
  - Entry phase, $\square_{ent}$
- Best acceptance over ±20° in entry phases (corresponds to time spread in the beam):
  G□15 MV/m, $\square_{ent}$□5°



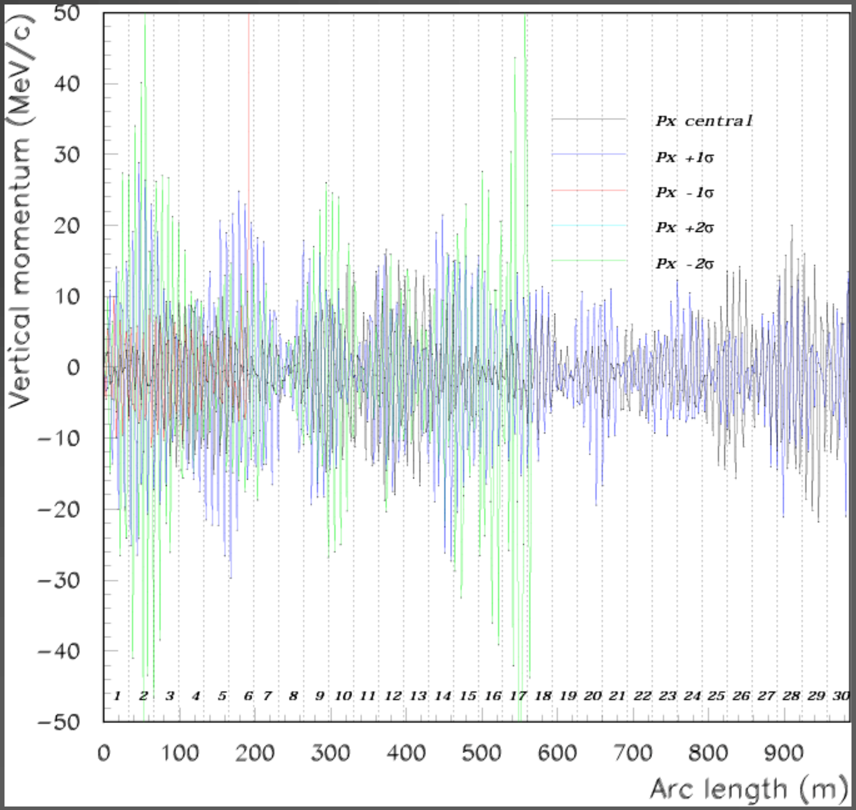
# Use realistic absorbers…

- Turn on all processes (except muon decay)

- Looks like a big mess!

  But only a few particles are shown here!

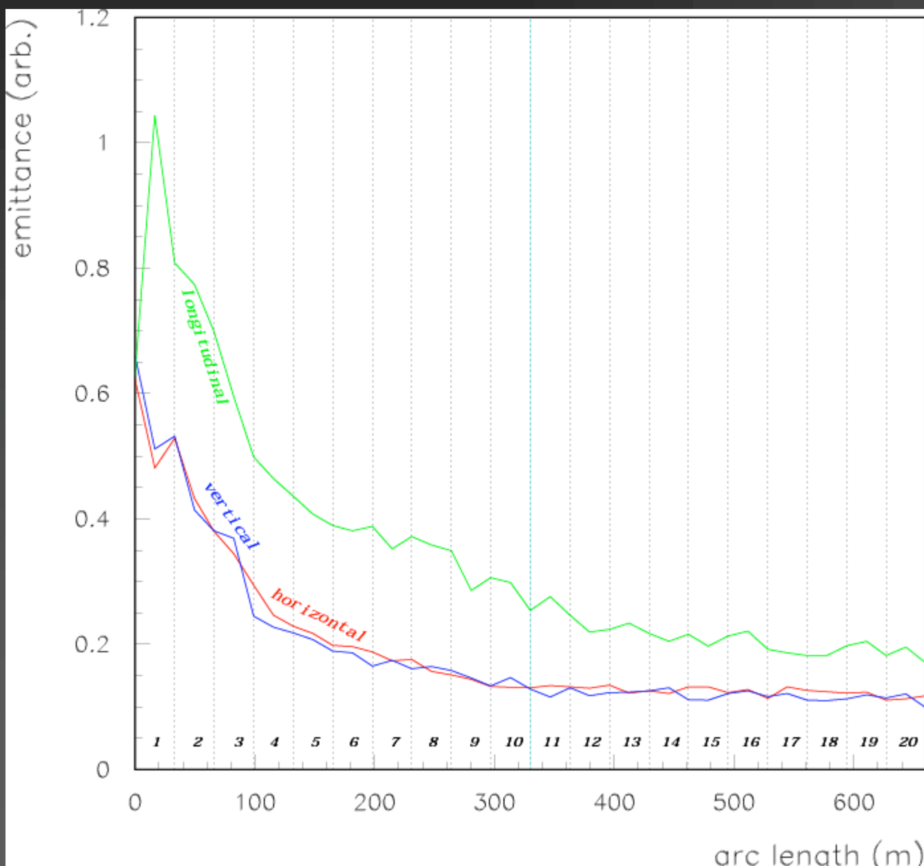
  To simulate cooling we need large statistics – a beam

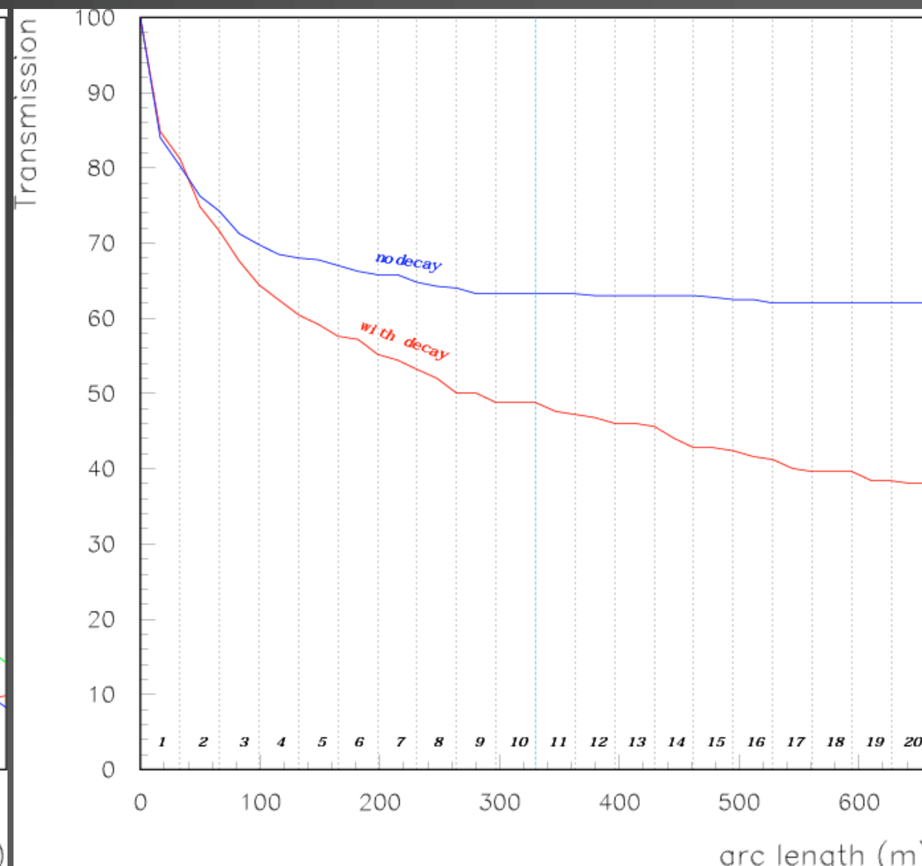


# The beam

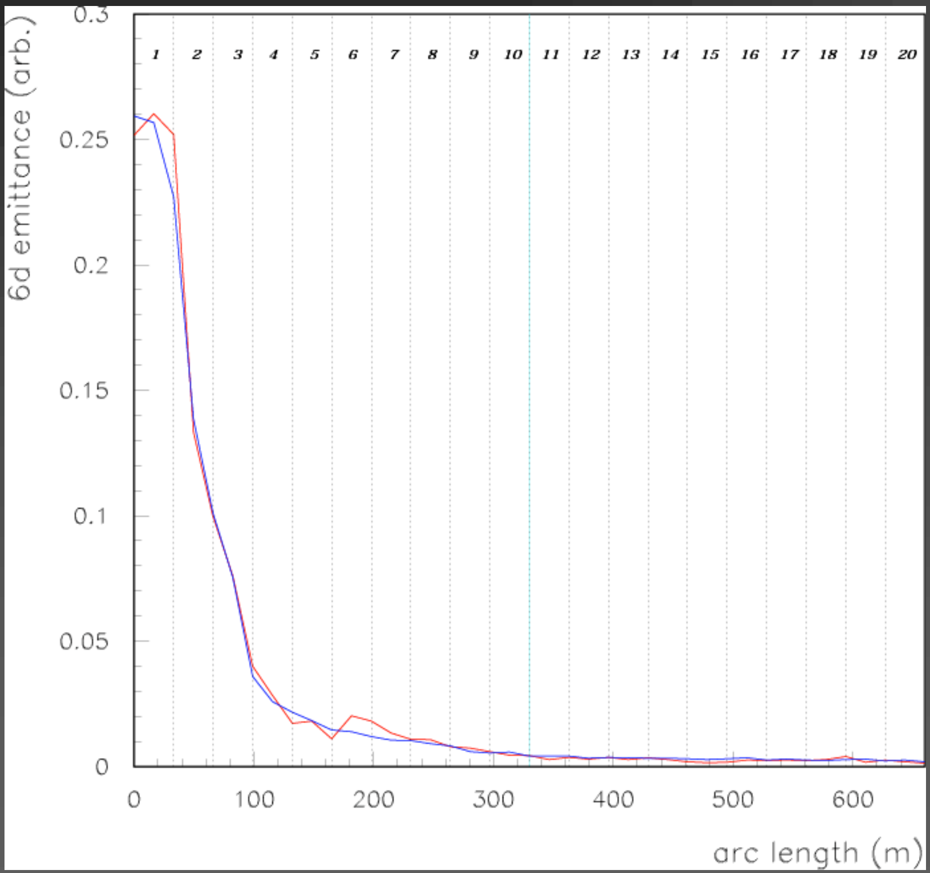
- Based on MC-Note 264,
- Gaussian distributions:
  - $\sigma_x = \sigma_y = 4.25$ cm
  - $\sigma_{px} = \sigma_{py} = 30$ MeV/c
  - $\sigma_z = 8$ cm ($\sigma_{cT} = 8$ cm in the Note)
  - $\sigma_{pz} = 22.5$ MeV/c ($\sigma_{\delta E} = 20$ MeV in the Note)
- Very preliminary cooling simulation:
  - Only 400 (250) muons without (with) decay
  - Emittance calculated from r.m.s. (no correlations)

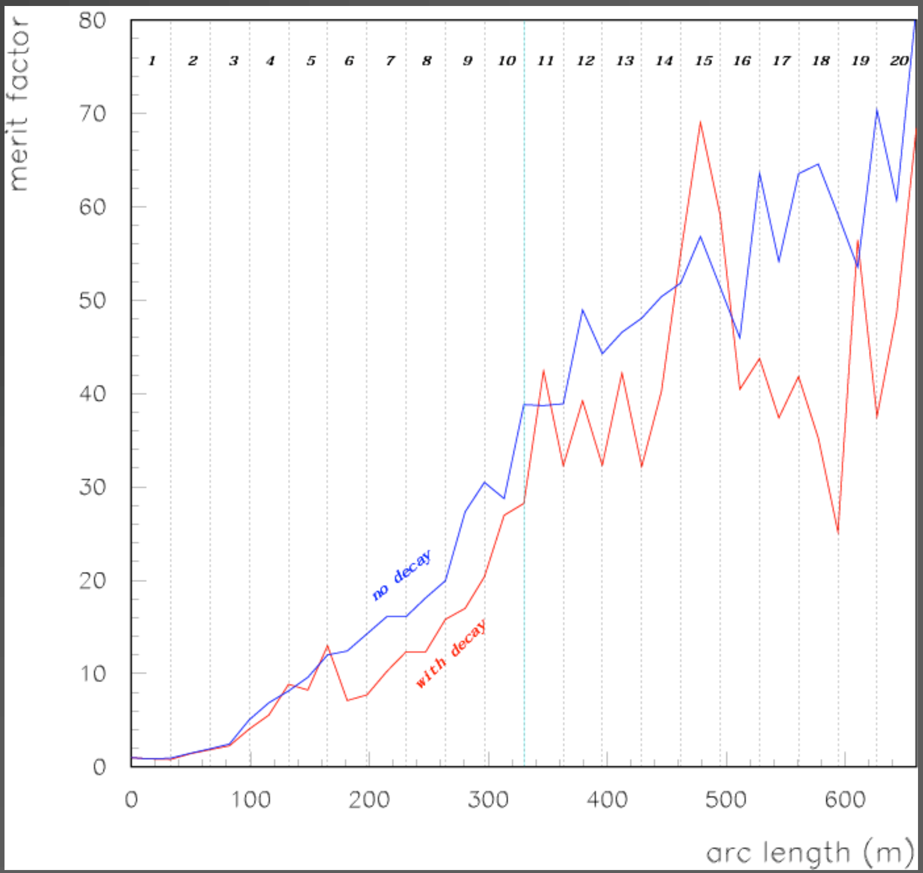
# Cooling performance – “emittances”, transmission



# Cooling performance – "6-D emittance", merit factor



# Performance after 10 turns in comparison to others

| | ICOOL (MC-239) | Balbekov (MC-264) | GEANT (current) |
|---|---|---|---|
| Transmission, no decay (%) | 61 | 70 | 63 |
| Transmission with decay (%) | 50 | 56 | 49 |
| Merit factor (w/ decay) | 50 | 55 | ~30 (about □2 less) |

# Conclusions

- First GEANT simulation of muon cooling in the RFOFO ring was performed
- Preliminary results: performance is comparable to other simulations (ICOOL, Balbekov)
    - Still, merit factor is about □2 lower
- To be done:
    - Increase statistics – use more particles in a beam
    - Calculate the emittance using ecalc9 (the right way to do it)
    - Other simulation improvements are considered
    - – in collaboration with R. Godang, S. Kahn